

AIR COMMAND AND STAFF COLLEGE

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**FUTURE ENABLERS: AIR FORCE SMART WEAPONS IN THE  
2040s**

by

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## **Abstract**

The Air Force will face many challenges over the next thirty years as it confronts budgetary limitations, increased costs, and heightened threats. The Air Force budget is likely to decrease. More of the Air Force budget will be allocated to pay for increasing personnel, maintenance, and operational costs. New weapon platforms will continue to be expensive and difficult to develop. This paper will explore these issues and examine the potential use of smart, stand-off weapons to address future Air Force problems and requirements.

Future stand-off weapons could allow the Air Force to pivot away from increasingly complex and costly weapons platforms. Compared to weapons platforms, stand-off weapons potentially offer faster development times, reduced costs, better value, and advanced capabilities. This paper will recommend that smart, stand-off weapons should play an important role in addressing future Air Force challenges while allowing it to maintain its combat effectiveness.

The United States Air Force will seek to retain a wide range of conventional and unconventional capabilities over the next three decades. But maintaining a broad military capacity will become increasingly difficult. Military spending is likely to decrease as it's displaced by non-discretionary spending. The Air Force will have fewer funds available for operations, manpower, and recapitalization. Additionally, more allocated funding will go towards personnel costs and benefits instead of towards weapons systems and war fighting capabilities. Likewise, current modernization programs will likely make it difficult to afford new combat systems due to cost overruns and development time increases. Reduced purchases of new combat systems will likely increase the costs of operating current systems longer. It will be difficult for the Air Force to deal with these issues without cutting readiness and capabilities.

The capabilities of current and future weapon systems will be challenged in future operational environments as well. Air Force investments in low-observable technologies will be at risk as adversaries acquire new methods for detecting low-observable aircraft. Once detected, aircraft survival will be placed in jeopardy by advanced surface-to-air missile (SAM) systems. Air Force aircraft will also be confronted with enemy anti-access weapons that seek to deny the United States entry into a combat theater. These new threats will make it increasingly difficult for the Air Force to use its combat power against enemy targets.

The Air Force will face numerous challenges over the next three decades. During that time, it's unlikely that the Air Force's overall operations tempo will decrease significantly as military requirements are largely dictated by political requirements; therefore, the Air Force will likely be required to do more with less. This begs the question: how will the Air Force be able to maintain an effective and versatile military capacity despite the numerous challenges?

These challenges will likely drive the Air Force to seek a variety of solutions to maintain

combat effectiveness. This paper examines one potential solution: it will recommend the development of inexpensive, precision stand-off weapons to confront future challenges faced by the Air Force. Future stand-off, smart weapons will offer improved capabilities over today's weapons; furthermore, they will have the capacity to be upgraded incrementally as needed.

### **Challenges Confronting the United States Air Force**

The Air Force will face numerous challenges over the next three decades. A chief problem is budgetary as the current budgetary climate portends less military spending in the future. The current total debt of the United States is over \$16 trillion.<sup>1</sup> Approximately \$11.2 trillion of the total debt is held by the public; the publicly held debt equates to 72.5 percent of the Gross Domestic Product (GDP).<sup>2</sup> Budget deficits have exceeded \$1 trillion over the past four years; there are few signs of a budget surplus in the immediate future.<sup>3</sup> The debt held by the public is expected to reach \$19.9 trillion in 2023 or roughly 77.0 percent of GDP.<sup>4</sup> The trend is towards greater public debt in the near term without substantial legislative enactments.

Public debt is expected to further increase over the next few decades due to long-term budgetary issues. Federal spending will continue to rise after 2023 under current laws as the federal budget must contend with an aging population, rising health care costs, and the scheduled expansion of health insurance subsidies.<sup>5</sup> The rising costs of associated health care programs and Social Security will dramatically increase federal debt relative to GDP unless spending is reduced in other areas, higher revenues collected, or a combination of the former options.<sup>6</sup> Expenditures on entitlement programs, health care, and debt service will likely increase over the next three decades<sup>7</sup>; this will limit the amount of money that can be spent on discretionary budget items such as national defense. The Air Force budget will be limited as the overall Department of Defense (DOD) budget shrinks.

The Air Force must contend with other budgetary restraints. More of the DOD budget has been diverted to pay for personnel costs. Since 2001, the number of active duty DOD personnel has increased eight percent while personnel costs have doubled.<sup>8</sup> Military pay and benefits have increased by 46 percent per person from 2001 to 2011.<sup>9</sup> In addition, the Military Health System (MHS) currently has 9.6 million eligible beneficiaries including active duty members, their families, dependent survivors, military retirees, and eligible Reserve component members.<sup>10</sup> MHS costs have doubled from \$19 billion in FY2001 to \$48.7 billion in the FY2013 budget request.<sup>11</sup> Although the DOD has taken steps to reduce military healthcare costs, the growth of personnel costs will severely constrain its spending options especially if personnel costs continue to grow faster than the overall defense budget.<sup>12</sup> Additional personnel costs will prevent defense spending in other necessary areas.

Budgetary restrictions and personnel costs will limit the amount of money the Air Force can spend on things such as training, readiness, and modernization.<sup>13</sup> The need for force modernization is particularly acute as recent wars, delayed procurement decisions, and contracting problems have prevented action. The Air Force will need to recapitalize much of its force in the coming decades. The two Air Force legs of the nuclear triad, bombers and land-based intercontinental ballistic missiles (ICBMs), are reaching the end of their service life and will need to be replaced.<sup>14</sup> The Air Force plans to develop and field 80 to 100 nuclear capable, long-range strike bombers in the mid-2020s to start replacing B-1 and B-2 aircraft.<sup>15</sup> The Air Force has begun looking into replacing its aging Minuteman III land-based ICBMs.<sup>16</sup>

The Air Force seeks to recapitalize much of its conventional forces as well. The Air Force is in the process of acquiring 179 KC-46A tankers to replace a portion of its Eisenhower-era KC-135 tanker fleet.<sup>17</sup> At the same time, the Air Force seeks to acquire over a thousand F-35

aircraft to replace older F-16 and A-10 aircraft.<sup>18</sup> The Air Force is also continually recapitalizing its space assets; the Air Force plans to invest or is investing in advanced extremely high-frequency (AEHF) satellites, space-based infrared systems (SIBIRS) satellites, weather satellites, space-based surveillance system (SBSS) satellites, and global positioning system (GPS) satellites.<sup>19</sup> Budgetary constraints may interfere with these and other Air Force modernization and recapitalization programs in the future.

The Air Force acquisition programs that remain funded will be under increasing pressure as the cost and complexity of acquiring new weapon systems has increased. Most current or near-term weapon systems acquisition programs have been both extremely costly and complex; this has often led to program cost overruns yielding fewer fielded systems with expensive per unit cost.<sup>20</sup> This trend is apparent in recent low-observable fighter acquisition programs.

The increasing complexity of low-observable aircraft has driven up acquisition time, program costs, and reduced buying power. It's not surprising that both the F-22 and F-35 programs have experienced lengthy development timelines and cost overruns that have resulted in reduced buying power as unit purchases decreased and unit costs increased. Development of the F-22 Raptor began in April 1991.<sup>21</sup> The F-22 reached initial operating capability 14 years later in December 2005.<sup>22</sup> Originally 750 aircraft were planned.<sup>23</sup> However, the \$65 billion program yielded only 187 aircraft; this equates to \$347 million per aircraft.<sup>24</sup> The 70 percent reduction in F-22 purchases almost tripled the per airplane cost resulting in a \$51.3 billion dollar loss in buying power for the entire F-22 program.<sup>25</sup>

The newest fighter acquisition program, the F-35 Lightning II, follows the same trend as the F-22. The DOD originally expected to procure 2,852 aircraft at \$81 million per aircraft when F-35 system development began in October 2001; however, as of March 2012, only 2,443

aircraft are expected to be procured at \$161 million per aircraft.<sup>26</sup> The program has not reached initial operating capacity and has been plagued by cost overruns, design issues, and delays.<sup>27</sup> The F-35 program has resulted in a reduction of buying power as the F-35 acquisition cycle has increased by years, planned F-35 purchases have decreased by over 14 percent, and F-35 unit costs have dramatically increased.<sup>28</sup> Already, the total F-35 program cost has increased by over \$73 billion.<sup>29</sup> Despite the costs and difficulties, military and political necessity has allowed large, low-observable aircraft programs like the F-35 to continue.<sup>30</sup> Therefore, cost increases are absorbed by decreasing aircraft purchases and driving up unit costs; this reduces buying power and the available operational combat power.

While the acquisition of new aircraft has proven expensive and complex, the cost of operating them has also increased. The DOD is the largest user of energy in the United States government; in FY2010 it accounted for 80 percent of the government's energy use.<sup>31</sup> Although DOD petroleum use has declined from FY2005 to FY2011, spending on petroleum increased 381 percent from \$4.5 billion in FY2005 to \$17.3 billion in FY2011.<sup>32</sup> Aircraft accounted for nearly 73 percent of the DOD petroleum use in 2003; thus, the Air Force used over half of the DOD's petroleum in FY2011.<sup>33</sup> Short-term increases in fuel costs are disruptive to the DOD budget and could reduce the money available to spend in areas such as operations and maintenance.<sup>34</sup> Also, long-term increases in fuel costs could potentially divert funding from procurement programs and other areas.<sup>35</sup> Long-term trends point to increasing and more volatile fuel prices.<sup>36</sup> The Air Force will be forced to contend with increasing fuel prices by spending more of its dwindling budget on fuel and, as a result, it will have less money to spend elsewhere.

Maintenance costs will also eat away at the Air Force budget. The average age of Air Force aircraft is already high: 22 years for fighters; 35 years for bombers; and, 47 years for

tankers.<sup>37</sup> As recapitalization efforts are delayed or reduced, the Air Force must make due by extending the life of older aircraft. Older aircraft cost more to maintain and operate as they require more extensive repair and remanufacture.<sup>38</sup> Programmed Depot Maintenance (PDM) costs increase as an aircraft ages; age adds failure modes and life limitations to an aircraft that reduces the time between depot cycles or increases the amount of maintenance work.<sup>39</sup> Furthermore, costly software and hardware additions and updates are often required due to operational necessity and to comply with the latest airworthiness directives and airspace qualification requirements.<sup>40</sup> The cost of operating and maintaining Air Force aircraft has increased even as the number of aircraft in the Air Force has decreased.<sup>41</sup> Even newer F-22 aircraft are proving difficult to maintain as its low-observable materials require twice the planned number of maintenance personnel.<sup>42</sup> Growing maintenance costs will strain future Air Force budgets leaving less money for other priorities.

The Air Force will be forced to contend with more challenging, high-threat environments in the future. The Air Force has set a goal to obtain only low-observable, fifth-generation fighters in the future.<sup>43</sup> Also, the next Air Force long-range bomber is expected to be a low-observable design.<sup>44</sup> However, low-observable aircraft may not be as effective in the coming decades as countermeasures are developed. There are many potential threats to low-observable aircraft. Low-observable aircraft are not truly invisible as they are designed to reduce radar detection ranges and be difficult to detect; this delays detection by enemy air-defenses and impedes the ability of fire control radars to acquire SAM firing solutions to shoot the aircraft down.<sup>45</sup>

However, new air-defense radar technologies and techniques will chip away at the ability of low-observable aircraft to survive future high-threat environments. Many nations seek to

counter low-observable technology.<sup>46</sup> One potential approach uses long-wavelength, very-high frequency (VHF) and ultra-high frequency (UHF) radars to detect and track low-observable aircraft.<sup>47</sup> Typically, long-wavelength radar systems, such as early warning radar systems, have difficulty achieving the precision necessary to provide adequate fire control solutions. However, newer long-wavelength radars incorporating active electronically scanned arrays (AESAs) and digital signal-processing may be able to detect and target low-observable aircraft.<sup>48</sup> These systems have the potential to improve their detection capabilities as computer processing power increases and AESA radars improve.

Passive radar is another approach that may counter low-observable technology. Airspace is filled with electromagnetic radiation emanating from a variety of sources such as radar arrays, television broadcast towers, cellular phones towers, and other transmitters; passive radar systems may be able to detect a low-observable aircraft by gathering and processing the electromagnetic radiation reflected by the aircraft.<sup>49</sup> Passive radar systems have the advantage of emitting no electromagnetic radiation; also, they can be easily camouflaged, difficult to locate and target, and produce no indications on friendly radar warning receivers.<sup>50</sup> Passive radar systems can operate in all weather conditions, have medium to long range, and can potentially detect, track, and target low-observable aircraft.<sup>51</sup> The VERA-NG by ERA, a Czech Republic company, is a current example of a passive surveillance system.<sup>52</sup> Passive radar systems are not without limitations as they require vast computer processing power to analyze electromagnetic radiation and distinguish real aerial targets from signal noise and clutter without generating false notifications.<sup>53</sup> The capabilities of passive radar system capabilities are bound to improve as computer processing power increases.

Passive listening systems also show potential for detecting low-observable aircraft.

These systems use aircraft emissions, such as radar, radio, or data link signals, to locate an aircraft's position; this information can then be passed to surveillance radars.<sup>54</sup> Low-observable aircraft are typically designed to avoid or reduce active aircraft emissions; however, improvements in signal-processing power may increase the ability of passive listening systems to detect low-observable aircraft.<sup>55</sup>

Infrared (IR)/electro-optical (EO) systems can be used to counter low-observable aircraft.<sup>56</sup> One type of IR/EO system is infrared search and track (IRST); it uses passive infrared sensors to detect and track heat sources.<sup>57</sup> Low-observable aircraft use a variety of techniques to mask their infrared signature; however, they remain vulnerable to IRST systems as the aircraft will always appear hotter than background levels.<sup>58</sup> EO systems have the capability to detect and track targets as well as provide day or night visual imagery for targeting.<sup>59</sup> However, IR/EO systems can be affected by clouds, low illumination, and low visibility.<sup>60</sup> Still, these sensors may prove useful against low-observable aircraft especially as sensor technology improves and computing processing power increases.

Low-observable aircraft face daunting challenges in the future as radars and other detection systems improve; this is especially true as radar and sensor advances are coupled with better signal-processing and sensor integration. In particular, passive sensor improvements will present significant challenges to low-observable aircraft as they become more effective and remain difficult to detect and target. Operating in a high-threat environment may prove difficult, if not impossible, for low-observable aircraft.

Detection capabilities will likely improve in the future along with the capabilities of systems designed to shoot down aircraft. Today, Air Force aircraft must contend with a variety of capable SAM systems. Aircraft that lack low-observable technology are unable to operate in

many current threat environments unless an enemy's integrated air defense system has been sufficiently degraded. Low-observable aircraft may eventually be detected by enemy surveillance systems and attacked at long-range by advanced SAM systems.

Current surface-to-air missile systems may already have the capability to target low-observable aircraft. The Russian S-400 Triumf (SA-21 Growler) air defense missile system represents one such system.<sup>61</sup> The S-400 is a medium to long-range surface-to-air system designed to destroy low-observable aircraft, cruise missiles, and ballistic missiles.<sup>62</sup> The system includes a digital, phased-array radar and uses digital radio networks to connect its missile batteries with its support systems.<sup>63</sup> S-400 missiles can reach a speed of three miles-a-second and engage targets up to 250-miles away at over 40-thousand meters altitude.<sup>64</sup> The S-400 also has a five-minute "shoot and scoot" capability enabling it to fire its missiles and quickly relocate to avoid counter-attack.<sup>65</sup>

Although the Russians will acquire the S-400 first, the system may eventually be exported to other nations.<sup>66</sup> A few nations may already have similar systems as the Chinese HQ-19 SAM system is believed to have been co-developed with or has parts taken from the Russian S-400 system.<sup>67</sup> Furthermore, other modern and highly capable SAM systems are currently available for export; they offer a lot of defensive capability for a relatively low price. The Russian company, Almaz-Antley, recently sold 15 batteries of S-300PMU-2 mobile SAM systems to China.<sup>68</sup> Each battery consists of two or three radar units and four missile launchers with four missiles per launcher.<sup>69</sup> The entire Chinese S-300PMU-2 purchase gives them 60 missile launchers and 240 missiles for roughly the same price as five F-22 Raptors.<sup>70</sup> Advanced SAM systems are likely to proliferate as nations perceive them to be a better value than purchasing low-observable aircraft. The proliferation of advanced SAM systems poses a direct

threat to low-observable aircraft now and in the future.

Future Air Force aircraft will need to contend with advanced air-to-air threats as well. The Air Force's monopoly on low-observable aircraft is nearing an end. Both the Russians and Chinese are actively developing low-observable aircraft. The Russian T-50 first flew in 2010 and has the ability to achieve supersonic cruise without afterburner.<sup>71</sup> While the T-50 design may have limited built-in stealth, it may use Digital Radio Frequency Memory (DRFM) to capture and rebroadcast radar signals in different frequencies to achieve some stealth by misleading enemy radar systems.<sup>72</sup> Also, the Russians are likely to equip the T-50 with Vympel R-37/AA-13 Arrow air-to-air missiles; these missiles can destroy targets 215-nautical miles away.<sup>73</sup>

The Chinese J-20 first flew in 2011 and appears to be a low-observable design, especially from the frontal aspect.<sup>74</sup> The J-20 is larger than the F-22 and may serve as an interceptor or strike aircraft against enemy bases, ships, or ISR systems.<sup>75</sup> It is expected to reach initial operational capability in 2018.<sup>76</sup> In 2012, the Chinese J-31 was unveiled and also appears to be a low-observable aircraft with features similar to the F-22 and F-35.<sup>77</sup> While these Russian and Chinese aircraft may not prove as capable as the Air Force's low-observable aircraft, the aircraft show that some nations are not standing still militarily and technologically. Adversary fighter aircraft may be able to prevent the Air Force from achieving air superiority or operating in contested airspace.

As integrated air defense sensors, SAMs, and adversary fighter aircraft improve, many Air Force aircraft will operate at greater risk in theater or will need to operate further from the fight--this is especially true of ISR aircraft, tankers, and other aircraft lacking low-observable technology. Furthermore, many potential adversaries will seek to deny the United States military

access to the theater entirely. China continues to develop the DF-21D anti-ship ballistic missile; this missile is designed to target moving ships, such as aircraft carriers, in excess of 1,500 kilometers.<sup>78</sup> Both the Chinese and Russians have a variety of anti-ship cruise missiles.<sup>79</sup> Also, other anti-ship missiles, like the French Exocet, exist in the hands of many parties.<sup>80</sup> These weapons would make it difficult for United States naval vessels, aircraft, and resupply ships to access and operate in future combat theaters.

Not only can ballistic, cruise, and guided missiles deny ships access to a combat theater, they can destroy, damage, and degrade the airfields and logistical support structure necessary to wage a successful air campaign. China is improving its ballistic missiles, cruise missiles, and aircraft in order to place regional targets, such as airbases and logistical facilities, at risk.<sup>81</sup> Other nations, like Iran, seek similar capabilities to deny the United States freedom of action.<sup>82</sup> The Air Force may be forced to flight at a distance if its theater airbases and logistical components are attacked; the attacks will greatly increase the complexity of Air Force air operations and decrease its effectiveness.

The Air Force will be challenged in many ways over the next three decades. Declining budgets and increasing costs will likely decrease the amount of available resources the Air Force has to meet future mission demands. Also, complex, low-observable aircraft that are expensive to develop, operate and maintain will likely become less effective. The Air Force will need to explore a variety of options to confront these future challenges and maintain effective combat capabilities.

### **Smart, Stand-Off Weapons**

In the face of these many issues, the United States Air Force should shift its focus away from complex, increasingly costly weapon platforms and hasten the development of new smart,

stand-off missiles over the next three decades. Stand-off weapons offer many advantages over weapon platform development: faster and easier development; reduced costs and better value; and, increased capabilities and effectiveness. Smart, stand-off weapons will contribute to increased operational flexibility while creating the desired effect at an efficient cost.

Smart, stand-off weapons avoid many of the problems associated with low-observable aircraft development. Stand-off weapons are weapons designed to be released by an aircraft at a safe distance away from a target; this allows the launch aircraft to avoid the risk of penetrating dangerous anti-aircraft defenses.<sup>83</sup> Traditionally, weapons lose accuracy the further they are released from their targets; therefore, many modern weapons avoid losing accuracy by incorporating guidance technology.<sup>84</sup> Various guidance technologies allow modern stand-off weapons to achieve a high degree of precision.<sup>85</sup> The use of precision weapons in combat has increased. Precision weapons accounted for only 9 percent of munitions expended in Operation Desert Storm; later, in Operation Enduring Freedom, they accounted for nearly 60 percent of munitions expended.<sup>86</sup> The use of smart, stand-off weapons is likely to increase as their costs decrease and capabilities improve.

Stand-off weapons by their very nature are smaller and less complex than low-observable aircraft. A fighter like the F-35 has thousands of components necessary to fly, navigate, communicate, identify targets, keep the pilot alive, launch weapons, and land. A smart, stand-off weapon needs to accomplish fewer tasks and, therefore, requires fewer components. The decreased size and complexity of stand-off weapons means that their development times are generally less than aircraft. For example, the program for the AGM-86A, the initial version of the Air-Launched Cruise Missile (ALCM), started in July 1973 and full-scale production was ordered in November 1976 before the program was eventually cancelled by the Carter

administration.<sup>87</sup> The AGM-129 Advanced Cruise Missile (ACM) was designed to be a stealthy replacement for the AGM-86 ALCM; the program began in April 1983 and the first production missiles were delivered to the Air Force in June 1990 and cleared for service in 1991.<sup>88</sup> More recently, the development of the stealthy, next-generation AGM-158A, Joint Air-to-Surface Standoff Missile (JASSM), started in April 1998 and was certified for operational use in September 2003; although the JASSM program suffered setbacks due to cost and reliability issues starting in 2004, production was eventually resumed in May 2008.<sup>89</sup> These weapon programs show that the development cycles of complex standoff precision weapons, even accounting for development delays, are shorter than the development cycle of recent low-observable aircraft.

Another advantage of smart, standoff weapons is that they can be more rapidly updated than low-observable aircraft as they are typically less complex. An analogy is that it's easier to develop or modify a computer application as opposed to redesigning an entire computer operating system. Stand-off weapons can be rapidly adapted to new operational environments. For example, the Air Force needed an accurate long-range conventional weapon after the difficulties experienced during the 1985 Operation El Dorado Canyon aircraft raid against Libya.<sup>90</sup> Thus, a program was started in July 1986 to convert nuclear warhead equipped AGM-86B ALCMs into missiles equipped with blast/fragmentation warheads.<sup>91</sup> The resulting AGM-86C, the Conventional ALCM (CALCM), was declared operational by January 1988; CALCMs have since been updated many times with improved guidance and warhead technologies.<sup>92</sup>

The United States Navy's AGM-84E SLAM is another example of a stand-off weapon that has been modified to improve its performance and provide new capabilities. The development of the AGM-84H/K SLAM-ER began in 1995 and the missile was declared

operational in March 2000.<sup>93</sup> The SLAM-ER uses many of the same basic components as the SLAM; however, the SLAM-ER was redesigned to improve its range, stealth, and precision.<sup>94</sup> It has more than double the range of the previous version, incorporates many guidance and software improvements, and has the ability to hit a moving ship.<sup>95</sup>

The Air Force hopes to achieve something similar with the JASSM-ER program. The JASSM-ER is a new version of JASSM that offers nearly double the range. JASSM-ER shares 70 percent of the hardware and 95 percent of the software with the original version.<sup>96</sup> Modifications are typical in many stand-off weapons programs as the initial system is modified to improve its capabilities and increase its ability to deal with new threats or operational environments.

Stand-off weapon systems are less costly to develop than low-observable aircraft. They tend to be less complex and, therefore, less expensive to develop. The DOD is expected to spend over \$9.1 billion in FY 2013 on the F-35 program to continue its development and acquire 29 aircraft.<sup>97</sup> In contrast, the amount the DOD plans to spend on all munitions and missiles in FY 2013 is \$10.3 billion.<sup>98</sup> Individual munitions and missile programs cost much less than the total amount; for example, the total cost of the JASSM program is expected to cost \$248.4 million in FY2013.<sup>99</sup> Because less money is spent on individual munitions and missile programs than on low-observable aircraft, if cost overruns occur, the overruns are substantially less in absolute dollar amounts. Although the JASSM program cost increased over 215 percent and roughly \$5 billion from 1998 to 2010, the total program cost increase of the F-35 program is much greater as the F-35 program cost increased over 34 percent and roughly \$73 billion from 2001 to 2010.<sup>100</sup> Substantial cost overruns for individual stand-off weapon programs do not affect the Air Force budget as much as overruns for low-observable aircraft programs. Furthermore, stand-off

weapon programs are more likely to get cut than aircraft programs if they underperform or are no longer needed. Finally, cost increases for stand-off weapon programs will likely be spread over more units than a low-observable aircraft program; therefore, the number of weapons procured can be reduced to keep the total cost within acceptable limits while still retaining most of the planned capabilities.

Stand-off weapons have another advantage over low-observable aircraft; stand-off weapons can be designed for storage until needed. While stored, little maintenance is required to keep the weapons available for use. Aside from minimal physical storage costs, Tomahawk Block III cruise missiles only need to be recertified and overhauled at a depot every six years; the process costs approximately \$180 thousand per missile.<sup>101</sup> The newer Tactical Tomahawk cruise missile is expected to have a 15-year recertification cycle and a 30-year service life.<sup>102</sup> Likewise, JASSM is planned to have a 15-year storage life.<sup>103</sup> This relatively low cost compares favorably to manned aircraft such as the F-22 that require constant upkeep. An F-22 undergoes 45 hours of maintenance for every hour it flies.<sup>104</sup> By 2015, the F-22 is expected to cost approximately \$50-thousand per flying hour and, when multiplied over its 8,000- hour expected service life, this equates to over \$396 million to operate and maintain a single F-22 during its lifetime.<sup>105</sup> Therefore, the costs to maintain and store stand-off weapons are dramatically lower than current manned fighter aircraft maintenance and operational costs.

Furthermore, once a stand-off weapon's planned service life is reached, a service life extension plan (SLEP) may be implemented to further extend its service life; currently, the service life of ALCM is being extended to 2030 under a SLEP.<sup>106</sup> Future stand-off weapons can be designed for increased storage time and low maintenance costs. Stand-off weapons could incorporate self-diagnostic software that reports potential issues while in storage; this could

resemble current remote engine monitoring systems that report airplane engine problems real-time to aid in fault diagnosis and maintenance.<sup>107</sup> If maintenance is required, line replaceable units or other methods could be used to ease of maintenance. Furthermore, stand-off weapons could be designed for easy software updates, component upgrades, and refurbishment. It may be possible to decrease already low storage and maintenance costs in the future.

Costs can be further reduced as stand-off weapon systems take advantage of commercial off-the-shelf (COTS) products. In the past, the military was a prime driver of technological advancements; now, the situation is reversed as the commercial sector technology is moving at a faster pace than military technology.<sup>108</sup> Purchasing COTS products for missile subsystems offers many advantages: lower costs, shorter development time, lower risks, proven performance, and access to advanced technology.<sup>109</sup> Whereas a military designed system can be developed to meet identified requirements, COTS products often provide an “80 percent” solution that can be quickly fielded with lower cost and risk.<sup>110</sup> Essentially, the military is able to leverage commercial sector research and development to reduce its own development and acquisition costs.

There are risks associated with COTS such as the failure of a COTS product to meet specifications, the potential lack of logistical support, the need for product modifications, and ensuring product availability over the lifetime of the military system.<sup>111</sup> Security is another potential issue as COTS software may include defects intentionally or unintentionally inserted into the program; also, COTS hardware may include counterfeit components vulnerable to exploitation or substandard components that may fail.<sup>112</sup> However, many of these risks can be mitigated through good program management.

Examples of COTS product use are plentiful in the DOD munitions acquisition programs.

For the JASSM program, Lockheed Martin, the prime contractor, wanted to make structural elements using composite material to save weight and enhance its low-observable qualities; however, using traditional aerospace composite materials would have rapidly escalated the cost of the missile as the materials cost from \$600 to \$1,000 per pound.<sup>113</sup> Fortunately, Lockheed Martin was able to modify and adapt vacuum-assisted resin transfer molding (VARTM), a process used to make fiberglass hulls for commercial pleasure boats, to produce the composite material for the JASSM for only \$120 per pound.<sup>114</sup> In addition, to save costs on the JASSM program, Lockheed Martin selected the same engine used to power the Harpoon anti-ship missile for over two decades; the engine vendor was able to further lower the engine costs by a third by replacing old military parts with modern and cheaper commercial parts and technology.<sup>115</sup> Future stand-off weapons will be able to use COTS products to reduce costs while improving capabilities.

Future stand-off weapons will likely benefit from new production techniques and materials. Three-dimensional printing is a technology that could change the way stand-off weapons are constructed in the future. A three-dimensional printer takes a computer blueprint and uses an additive process to build up a desired object by depositing material from a nozzle or selectively solidifying thin layers of plastic or metal.<sup>116</sup> Newer machines are able to use a broad range of materials including production-grade plastics and metals.<sup>117</sup> The precision of three-dimensional printers continue to improve. It is now possible to print items on the micrometer scale.<sup>118</sup> The size of the item produced is limited primarily by the size of the three-dimensional printer; thus, large items such as aircraft components are possible.<sup>119</sup>

In the future, three-dimensional printers may offer many advantages over traditional manufacturing methods used to construct smart-standoff weapons. Three-dimensional printers

may reduce costs by getting rid of production lines.<sup>120</sup> The additive manufacturing process reduces waste and may require only one-tenth the material as conventional manufacturing.<sup>121</sup> New, more efficient designs are possible as it can create items in shapes impossible to manufacture using conventional techniques.<sup>122</sup> A single item can be produced quickly and cheaply with little risk or concerned about achieving economy of scale.<sup>123</sup> Three-dimensional printers will likely reduce the cost, decrease the development time, and improve the capabilities of future stand-off weapons. Three decades in the future, it is possible that large parts of stand-off weapons will be produced using three-dimensional printers.

Smart, stand-off weapons will become increasingly important over the next three-decades as they will offer many advanced capabilities. A key advantage of stand-off weapons is that they allow force to be applied at a distance without subjecting the launch aircraft to enemy defenses. Already, the JASSM-ER is being developed to have a range in excess of 500 miles;<sup>124</sup> this baseline range extends beyond the range of most current enemy defense systems. The range of future weapons could be increased as engine, material, and aerodynamic technologies improve. Increased range will help prevent skilled pilots from losing their lives in manned aircraft as stand-off weapons can be fired outside of the range of current and future enemy threats. Also, for both man and unmanned aircraft, stand-off weapons will lessen the risk of losing more expensive and hard to replace aircraft. Increasing stand-off weapon range may also increase sortie generation rates as a launch aircraft will be able to deploy its weapons at a distance from the target but closer to its airbase; this allows an aircraft to quickly return to base to rearm, refuel, and swap its aircrew. This capability could help bridge the distances encountered in the Pacific.

In the past, precision munitions were typically launched from manned combat aircraft

such as fighters or bombers. However, as the MQ-1 Predator has shown, precision weapons can be launched from a variety of airframes including unmanned aircraft. The types of aircraft carrying precision weapons could be expanded in the future as the weapons themselves become more intelligent, autonomous, and better able to guide themselves to distant targets. Stand-off weapons have already demonstrated their ability to accurately navigate to a target; furthermore, precision weapons, such as Lockheed Martin's Low Cost Autonomous Attack System (LOCAAS), have even achieved a level of autonomy.<sup>125</sup> Air Force cost savings may be achieved by decreasing future purchases of expensive, low-observable fighter and bomber aircraft as future stand-off weapons may be launched from a variety of other less expensive and more versatile aircraft.

Cargo aircraft such as the C-130, C-17, or C-5 could be equipped to carry and air-drop palletized long-range stand-off missiles safely out of range of enemy defenses; this could improve operational flexibility, weapons range, and dramatically increase the amount of weapons able to be thrown at an enemy. Also, using cargo aircraft to launch stand-off weapons would free up low-observable aircraft for other higher priority tasks as they are relatively few in number, carry a small number of weapons internally, and have limited range without tanker support. Cargo aircraft already have a proven ability to launch weapons. In October 1974, a C-5A Galaxy successfully deployed a weapon when it airdropped an operational Minuteman I ICBM over the Pacific.<sup>126</sup> More recently, in July 2011, a C-17 successfully launched a Short Range Air Launched Target (SRALT) missile to test missile defense technologies.<sup>127</sup> These demonstrations show the potential of using cargo aircraft to launch long-range stand-off weapons. Remotely Piloted Aircraft (RPA), Unmanned Aerial Vehicles (UAVs), Blimps, and other aerial vehicles may also be used to launch stand-off weapons.

Future stand-off weapons will likely be launched from a variety of aerial vehicles and offer many improved capabilities. Data links and other communication methods may allow the stand-off weapons to be retargeted mid-flight or communicate with other weapons. Networked smart-weapons could have a variety of capabilities: the weapons could swarm enemy defenses and targets; reallocate themselves to different targets to compensate for destroyed, malfunctioning, or intercepted weapons; change flight profiles and tactics in response to enemy defenses; coordinate strikes to concentrate or achieve specific weapon effects; or, if necessary, instruct the weapon to self-destruct.

Already, stand-off weapons such as the JASSM-ER are being designed to incorporate two-way data links to allow them to be retargeted in mid-flight and aide with bomb impact assessment.<sup>128</sup> In one simulated combat mission, two Boeing X-45 Joint Unmanned Combat Air Systems (J-UCASs) demonstrated the ability to autonomously work together and detect, engage, and destroy unexpected threats.<sup>129</sup> Although J-UCAS is a weapon launch platform, it is foreseeable that future stand-off weapons may gain similar abilities to deal with unexpected situations. Also, like the J-UCAS, future stand-off weapons may be data linked and networked to coordinate their actions and share information.

Improved guidance and targeting systems will enable increased accuracy, reliability, and weapon effectiveness. When the AGM-86B ALCM entered service in 1982, its guidance system compared terrain elevation contour samples with digital map data to update its inertial navigation system (INS); this provided it with a circular error of probability (CEP) accuracy of 30-meters.<sup>130</sup> Later, Block 1A AGM-86C CALCMs incorporated an eight-channel GPS receiver with improved anti-jamming capability and achieved an accuracy of three-meters CEP.<sup>131</sup> JASSM incorporates further guidance improvements. It uses an INS/GPS unit coupled with an imaging

infrared (IIR) seeker that provides terminal guidance; the missile should be accurate to within three-meters CEP.<sup>132</sup> JASSM's IIR seeker also has autonomous target recognition capabilities and uses three-dimensional models coupled with the GPS coordinates of the intended target to further improve accuracy.<sup>133</sup>

Future stand-off weapons will likely incorporate navigational systems such as INS and multi-channel, jam resistant GPS; these systems will likely provide accuracy that rivals or improves upon current navigational systems but in a smaller, less expensive package. Presently, the Miniature Integrated Navigation Technology (MINT) program seeks to design a GPS/INS system that is as accurate as current designs but is smaller, lighter, less expensive, and more resistant to countermeasures.<sup>134</sup> Also, various forms of terminal guidance sensors will further increase weapon accuracy in all weather conditions, aide the weapon in striking moving targets, allow the weapon to strike targets at selected points, and increase its ability to select targets autonomously. The Air Force Research Laboratory (AFRL) is presently funding several terminal guidance sensor programs to include laser radar (LADAR) and other seekers.<sup>135</sup> Advances in terminal guidance sensors will help to improve the accuracy and effects of future stand-off weapons.

Recent warhead improvements have allowed for greater explosive power in smaller packages; these advances will improve the capability of future stand-off weapons. JASSM's warhead weighs 1,000 pounds but it is designed to have the same explosive effect as a 2,000 pound warhead.<sup>136</sup> The penetration ability of warheads has improved as well. The GBU-39/B Small Diameter Bomb (SDB I) weighs only 250 pounds but it can penetrate more than a meter of steel-reinforced concrete.<sup>137</sup> Improved warhead designs are a key enabler of future stand-off weapons as smaller, more powerful warheads, similar to the one found on the SDB I, will allow

stand-off weapons to be lighter, carry more fuel, and have longer range if necessary. Achieving the proper warhead effect has increasingly become more important than warhead size.

A variety of effects can be produced depending on the warhead or payload. Thermobaric warheads may be used by stand-off weapons; these warheads use heat as high as 3,000 degrees Celsius and blast pressure that travels approximately 10,000 feet per second to destroy targets.<sup>138</sup> High-powered microwave (HPM) warheads may be fitted to stand-off weapons to damage or disable electronic components within the effective radius of its electromagnetic pulse.<sup>139</sup> Carbon filament warheads may also be employed; these warheads use thousands of long, very fine carbon-fiber wires to short circuit parts of an adversary's electrical system.<sup>140</sup> HPM and carbon filament warheads were allegedly used in the first Gulf War.<sup>141</sup> Future stand-off weapons may eventually carry multiple deployable warheads and smart sub munitions such as the previously mentioned LOCAAS.<sup>142</sup> LOCAAS is a miniature, powered munition; it has the autonomous ability to loiter and search a broad area with its sensors, identify a target, and destroy the target even if it is moving.<sup>143</sup> Future stand-off weapons may be equipped with a variety of warheads and payloads to achieve a planned effect.

In the immediate future, most stand-off weapons will remain subsonic; however, as technology improves and enemy defenses become more formidable, high supersonic and hypersonic stand-off weapons may be employed. Hypersonic missiles have already begun to be tested. The HyFly missile program began flight testing in 2005; the program sought to design, build, and test a hypersonic air vehicle with a maximum sustainable cruise speed in excess of Mach 6.<sup>144</sup> The Air Force seeks to demonstrate a high-speed strike weapon by FY2017.<sup>145</sup> Hypersonic technology may eventually be incorporated into future stand-off weapons three decades from now. Hypersonic, long-range missiles may provide a means of attacking time

sensitive or hardened targets.

Smart, stand-off weapons will become increasingly useful in future conflicts as they will offer a wide range of capabilities. However, smart weapons are not without their limitations. A precision weapon is only as smart as the intelligence used to target it; accurate intelligence is required to ensure the weapons are properly targeted. Also, stand-off weapons are reliant on launch platforms; basing and logistical support for the launch platforms will still be necessary even if the amount of expensive, low-observable launch aircraft is decreased. Finally, stand-off weapons may be vulnerable to countermeasures; tactics and technology will continually need to be modified to counteract weapon system vulnerabilities.

Current stand-off weapons are adequate for many potential conflicts. Improvements will keep them relevant near term. However, as adversary air defenses improve over the next three decades, the development and production of the next generation of stand-off weapons incorporating the latest technological advances will need to begin by the mid-2030s in order to field operational weapons by the early-2040s. Before that time, the Air Force should begin to shift its focus away from developing ever more expensive launch aircraft and begin expanding the variety of aircraft capable of launching stand-off weapons. Furthermore, the Air Force should increase relevant stand-off weapon research in fields such as miniaturization, communication, guidance, warhead design, and explosives to enable future advanced capabilities.

The only constant over the next thirty years will be change. During this period, the Air Force will face many challenges. Budgetary pressures will likely reduce defense spending. The Air Force budget will be constrained by growing personnel, acquisition, maintenance, and operational costs. In addition, Air Force aircraft may be forced to confront new and improved

enemy threats. Therefore, instead of procuring expensive, low-observable aircraft, the Air Force should place a greater priority on developing new stand-off weapons in the future. Stand-off weapons offer many advantages such as faster development, better value, and improved effectiveness. Smart, stand-off weapons could allow the Air Force to address many future challenges while maintaining or improving its overall combat effectiveness.



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